

**THE EFFECTS OF FATIGUE ON REACTION TIME DURING
SUDDEN ANKLE INVERSION**

by

Nicole D. Jackson

A thesis submitted to the Faculty of the University of Delaware in partial fulfillment of the requirements for the degree of Honors Bachelor of Science in Athletic Training with Distinction.

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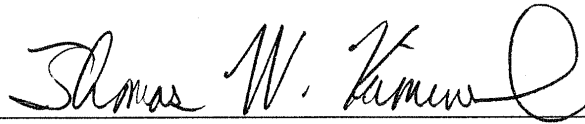
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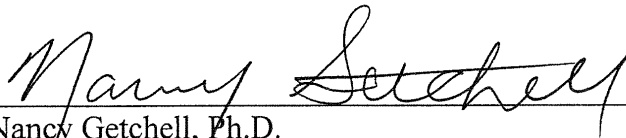
Approved:



Thomas W. Kaminski, Ph.D.

Professor in charge of thesis on behalf of the Advisory Committee

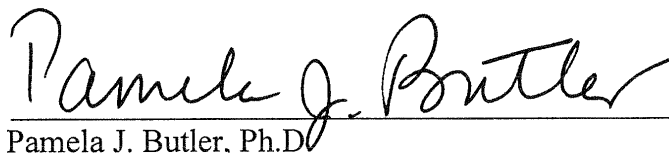
Approved:



Nancy Getchell, Ph.D.

Committee member from the Department of Health, Nutrition, and
Exercise Sciences

Approved:



Pamela J. Butler, Ph.D.

Committee member from the Board of Senior Thesis Readers

Approved:

John A. Courtright, Ph.D.

Director, University Honors Program

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ABSTRACT

Inversion ankle sprains are the most common orthopedic injury incurred during sports participation. The peroneal muscles act to stabilize the ankle during inversion moments. A better understanding of the reaction time of the lower leg muscles in response to inversion stress after fatigue may help decrease the incidence of ankle injury. The purpose of this study was to evaluate the effects of fatigue on reaction time during sudden ankle inversion. Ten males and 10 females with no previous history of lower extremity injury were recruited to participate. Reaction time, defined as the time between the onset of inversion movement and the onset of EMG activity, of the peroneus longus (PL), peroneus brevis (PB), and tibialis anterior (TA) muscles was recorded in response to a sudden inversion perturbation. A fatigue intervention was administered using the Kin Com isokinetic dynamometer in the eccentric (ECC) – concentric (CON) mode for the eversion motion at 120°/s. The subject performed repetitive ECC – CON eversion ankle motions until ECC force production dropped below 50% of maximal ECC force. Posttest reaction times were recorded. Contrary to the initial hypothesis, reaction time significantly decreased for the PL and PB ($P < 0.0125$), but not the TA, after fatigue. A significant decrease in reaction time indicates improvement following fatigue, which may result from increased muscle spindle sensitivity. A study of total motor time, which includes reaction time and electromechanical delay, may offer a better understanding of the effects of fatigue on reaction time.

Chapter 1

INTRODUCTION

Ankle Injuries

Orthopaedic injuries are a significant health related problem. These injuries most often occur during sports participation when the body is placed in vulnerable positions. Ankle injuries are the most common orthopaedic injury incurred during sport participation.^{1,2} It has been estimated that more than 23,000 ankle sprains occur in the United States per day,¹ accounting for 10-45% of all sports related injuries;³⁻⁶ 85% of these injuries involve the lateral ligaments.⁴⁻⁹ When an injury to the lateral ligament complex occurs, the inversion force exceeds the eccentric eversion force generated by the peroneal muscles¹⁰ and, as a result, the lateral ligaments, muscles, and nerves are stretched and possibly torn. The disruption of these structures often leads to mechanical instability, peroneal muscle weakness, and a decrease in neuromuscular control mechanisms about the joint, leaving it particularly susceptible to further injury.^{4,5,7,8,10-17} In fact, recurrent sprains have been reported in 15-80% of patients who had previously sustained an inversion ankle sprain.^{4-8,10-12,17-19} Braun¹⁸ reported residual symptoms in 72.6% of patients 6 to 18 months following the original injury. Additionally, Anandacoomarasamy et al.⁶ reported 74% of patients described persisting symptoms 1.5 to 4 years subsequent to the initial injury. Recurrent sprains, residual disability, a feeling of giving way, and a sensation of joint weakness characterize functional ankle instability, a condition that often arises secondary to ankle trauma^{5,7,8,10,15,17} Repeated ankle sprains associated with functional ankle

instability have been linked to an increased risk of osteoarthritis and articular degeneration.¹ In a study of 607 patients being treated for severe osteoarthritis (OA), 6.5%⁴⁰ were being treated for ankle OA.²⁰ Of those patients being treated for ankle OA, 93% of the cases were attributed to a previous ankle injury, termed secondary OA, as compared to 31% and 15% in the hip and knee, respectively. Given that the majority of ankle OA cases occur secondary to ankle injury, it may be inferred that preventing ankle injuries will lead to a decreased incidence of ankle OA and the associated disability. Due to the significant amount of time lost from sport, work, and leisure-time activities, research on the factors that contribute to ankle injuries is warranted.

Neuromuscular Control

Neuromuscular control can be defined as the interaction between the nervous and musculoskeletal systems to produce a desired effect, specifically in response to a stimulus. During activity, dynamic and static restraints work together, via feedforward, reactive, and voluntary mechanisms, to maintain correct joint configuration in response to forces imposed on the joint.²¹ In the ankle specifically, the lateral ligaments are highly innervated by mechanoreceptors,^{11,13} which perceive a stretch when the foot is forced into inversion and send an afferent signal to the spinal cord. Reflexively, the spinal cord sends an efferent signal to the γ -motor neuron of the muscle spindle in the peroneal muscles, which sensitize the muscles to stretch. Once the muscle is stretched, the muscle spindle reflex creates a contraction in the muscle to oppose the stretch.²² Many researchers have studied this reflex both as a function of peroneal reaction time^{3-5,7,8,10,13,15-17,23,24} and electromechanical delay^{10,21,25} yet there is a great deal of controversy in the literature as to the exact role that this reflex plays in

preventing ankle sprains. Some authors suggest that the peroneal reaction time is critical to ankle health given that peroneal reaction time has been shown to be significantly delayed in subjects with ankle instability.^{10, 15, 26-29} Conversely, there is some evidence that suggests there is no significant difference in peroneal reaction time in individuals with ankle instability when compared to both uninjured controls and the contralateral uninvolved limb.^{4,30,31} Thus, peroneal reaction time alone cannot explain ankle instability and other factors must be addressed.^{4,5,7,8,17,23,24} In a study comparing electromyographic (EMG) responses to landing on inverting and non-inverting surfaces in normal subjects, Gruneberg et al.³ reported that when landing on a horizontal surface all lower leg muscles were equally active: however, when landing on an inverting surface the peroneus longus and peroneus brevis muscles were relatively more active, when compared to the other lower leg muscles (soleus, gastrocnemius, and tibialis anterior), indicating that the peroneal muscles are the primary dynamic restraint against inversion moments. Given the inconsistency of the results in studies involving subjects with unstable ankles and the lack of research on the body's normal response to inversion sprain mechanisms, studying the peroneal muscle reflex of normal subjects in response to stress may be imperative in determining the cause of ankle sprains and long-term dysfunction as well as lead to preventative initiatives and improved treatment measures.

Fatigue

Some suggest that fatigue plays a significant role in the occurrence of ankle injuries.^{25,32-36} Anecdotally, many ankle injuries occur during the latter stages of activity when fatigue is present. There are two types of fatigue, central and peripheral.^{33,35,37} Central fatigue occurs when there is a reduction in the number of

new motor units recruited and/or a decrease in the firing frequency of the already active motor units.^{35,37} Peripheral fatigue, which occurs beyond the neuromuscular junction, is due to diminished efficiency of the contractile unit of the muscles.^{35,37} Whether the onset of fatigue occurs centrally or peripherally, many researchers have documented notable decreases in the neuromuscular feedback system of the joint around which the fatigued muscles are located.^{21,25,32-34,38,36-39} Many of these studies, however, focused on the EMG profiles^{33,37,39} and postural control during static balance.^{32,34,36,38} Moore et al.²¹ evaluated the differences in response timing and amplitude of the patellar-tendon-tap reflex between males and females as a function of fatigue and found significant increases in total motor time, which includes the pre-motor time and the electromechanical delay, for females after fatigue, but males showed no change. Yeung et al.²⁵ also studied changes in neuromuscular control in the knee by examining the total reaction time in the vastus medialis muscle and found a significant decrease in premotor time, a significant increase in electromechanical delay, but no significant change in total reaction time. No such studies have evaluated the response times of the ankle musculature to ankle inversion stress before and immediately after isokinetic fatigue.

Generally, isokinetic fatigue has been defined as a force production decrease below 50% of the peak force, which is determined either from a pretest maximal isometric contraction or peak force observed during the first three to five contractions in the fatigue protocol.^{34,38,40} Isokinetic force output is significantly greater for eccentric (ECC) than concentric (CON) muscle actions, while EMG activity is significantly greater for CON than ECC actions. In other words, ECC muscle activity can produce more force with less nervous stimulation, effectively

decreasing the amount of energy required to perform the task.³³ Under fatigued conditions, CON muscle actions result in a greater loss of force than ECC actions.³³ Therefore, in this study, fatigue was measured via a decrease in ECC force production because ECC muscle actions are more resistant to force losses due to fatigue. Furthermore, ankle inversion injuries are caused by an inability of the peroneal muscles to eccentrically resist the inversion movement.¹⁰ Traditionally, isokinetic fatigue protocols have utilized CON movements solely, whereas unique to this study, fatigue was measured by decreases in ECC force production.

While many studies have evaluated peroneal reaction time, comparing healthy and injured ankles,^{3-5,7,8,10,13,15-17,23,24} a better understanding of peroneal muscle responses to inversion stress in healthy subjects may help researchers clear up the discrepancies in the literature and identify risk factors that may lead to ankle inversion sprains. Furthermore, examining gender differences may help to identify if any gender related deficiencies exist in the ankle, like the anterior cruciate ligament deficiency in the knee for females. The purpose of this study was to measure the effects of fatigue on reaction time in the ankle musculature when responding to a sudden ankle inversion perturbation. A secondary purpose was to examine differences in reaction time between genders. For the purposes of this study, fatigue is defined as a 50% decrease in isokinetic force production of an ECC eversion movement as determined from the average peak force produced during three maximal isokinetic ECC eversion repetitions. It was hypothesized that fatigue would increase reaction time; therefore, the subjects would respond more slowly to the inversion movement. A second hypothesis was that there would be no differences in reaction time between genders.

Chapter 2

MATERIALS AND METHODS

Subjects

A total of twenty subjects, 10 males (age: 20.7 ± 2.2 yrs, height: 175.8 ± 5.9 cm, mass: 76.2 ± 10.1 kg) and 10 females (age: 19.7 ± 1.3 yrs, height: 167.5 ± 8.4 cm, mass: 68.9 ± 10.4 kg), were recruited from the university community. All subjects filled out an ankle inclusion questionnaire (Appendix A) to identify any exclusion criteria. In order to be included, the subjects had to be free of any lower extremity injury. Specifically, subjects should never have suffered an injury on their dominant ankle in their lifetime. All subjects gave their written informed consent (Appendix B) approved by the Human Subjects Review Board (HS 06-077: Appendix C) before participation in the study.

Instrumentation

EMG activity was recorded in the tibialis anterior (TA), peroneus longus (PL), and peroneus brevis (PB) muscles using bipolar surface electrodes (Ag-AgCl, 6 mm contact diameter, 2 cm spacing). The raw EMG data were collected and amplified (input impedance 10 M Ω , gain 5000x, common mode rejection ratio > 115 dB) using a Bortec AMT-8[®] EMG system (Bortec Biomedical Ltd., Calgary, Alberta, Canada). The EMG signals were collected using a laptop computer with a 12-bit analog-to-digital converter (6024-E, National Instruments Corp., Austin, TX), at a sampling rate

of 1000 Hz, using custom designed Labview software (version 7.1, National Instruments Corp., Austin, TX) to synchronize and save the data for future analysis.

The Kinetic Communicator (Kin Com) 125-AP isokinetic dynamometer (Chattecx Corp., Chattanooga, TN) was used to induce fatigue. The dynamometer was operated in isokinetic mode, and thus quantified resistive force generated by the subject, concentrically and eccentrically, at a preset angular velocity for the eversion motion at the ankle.

The sudden inversion movement was produced by a device constructed and used by Beckman and Buchanan⁵. (Figure 2.1) The platform was constructed such that each ankle could be inverted independently. Pneumatic actuators drove the platforms, while the angle of inversion was measured by potentiometers located at the axis of rotation. The platforms were inverted to 27° - 30° of inversion at a velocity of 500°/s - 700°/s about an axis located near the subtalar joint and midtarsal joint axes.⁵ Device movement was initiated using a custom trigger that delivered a TTL (Transistor-Transistor Logic) pulse with a duration of 100 ms.

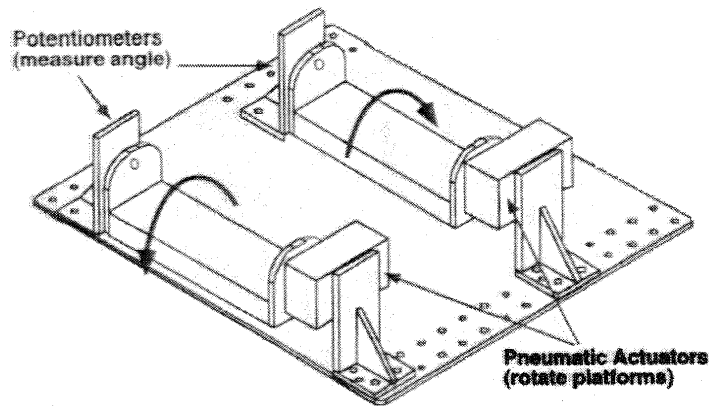


Figure 2.1 Inversion perturbation device as pictured in Beckman and Buchanan.⁵

Procedure

Each subject reported for testing on one occasion that lasted approximately one hour. Subjects were asked to read and sign the informed consent before participation. Once consent was obtained, mass and height were measured and recorded followed by a stationary bicycle warm-up for 5 minutes. Specific patches of skin on the lower leg were shaved (if necessary), abraded, and wiped with an alcohol pad prior to electrode placement. Electrode placement was established via finger and handbreadths detailed by Perotto⁴¹, over the TA, PL, and PB muscles. The electrode over the TA was placed four fingerbreadths distal to the tibial tuberosity and one fingerbreadth lateral to the tibial crest. The electrode over the PL muscle was located three fingerbreadths distal to the head of the fibula and along the lateral edge of the fibula. The electrode over the PB was positioned one handbreadth proximal to the lateral malleolus and one fingerbreadth anterior to the PL tendon. The adhesive electrodes were oriented parallel to the direction of the muscle fibers and affixed to the

leg. The EMG leads were connected to the EMG pack, which was fastened around the waist and connected directly to the EMG system.

The subject then stood barefoot on the ankle inversion device with the feet placed comfortably on the platforms facing away from the researcher to eliminate any visual stimulus with regard to the trigger switch. The subject was asked to stand normally on the platforms and remain facing the wall for the duration of the pretest. (Figure 2.2) Each subject was given the opportunity to feel the sudden inversion perturbation once on each leg before data acquisition began. Once the subject felt comfortable on the device, the pretest commenced and ten trials were recorded on the dominant ankle, as determined by asking with which leg the subject would kick a ball.

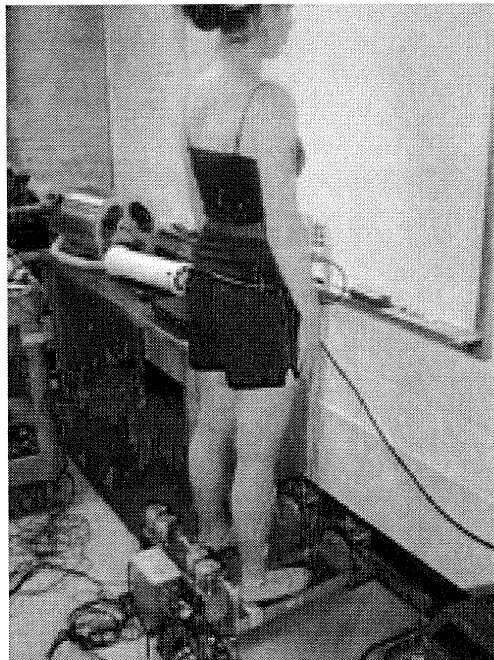


Figure 2.2 Subject positioning during inversion perturbation both pre and post fatigue.

Prior to fatiguing the evertors, the subject was positioned in the Kin Com isokinetic dynamometer for inversion/eversion movements for the dominant leg with the knee in 45° of flexion and the foot firmly fixed to the shoe plate wearing shoes. (Figure 2.3) A warm-up consisting of several submaximal repetitions was performed to familiarize the subject with the CON-ECC eversion movement required for testing. The subject then performed three CON and three ECC maximal isokinetic repetitions at a velocity of 120°/s. Using the “overlay” feature on the Kin Com, each repetition was performed separately with a 5 second delay between repetitions. The repetitions were averaged and a peak torque was determined for the ECC muscle action, from which 50% of the maximal ECC force production was determined. The subject then performed continuous CON and ECC eversion ankle movements, to isolate the peroneal muscles, at 120°/s until the ECC force production dropped below 50% of maximal ECC force production for three consecutive repetitions. It was at this point that the subject was considered fatigued and the exercise ceased.

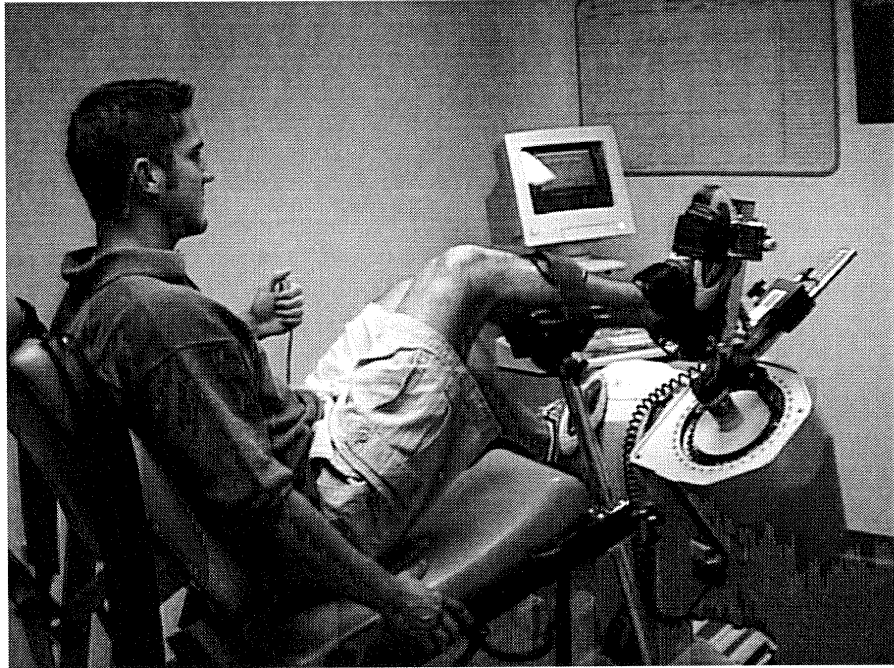


Figure 2.3 Subject positioning during fatigue intervention on the Kin Com.

Once fatigue was attained the subject was positioned back on the ankle inversion perturbation device barefoot in the same manner as the pretest. Ten posttest trials were conducted on the fatigued leg. All posttesting was performed within 5 minutes of completion of the fatiguing event.

Data Analysis

The onset of motion was determined as 10 standard deviations above the baseline potentiometer reading, and onset of muscle activity was determined as 10 standard deviations above baseline EMG activity. The EMG data were band-pass filtered (2nd order, zero-lag, Butterworth filter, with cutoff frequencies of 10 Hz and 500 Hz). All data were visually inspected to assure that the determination of EMG and movement onset was an accurate representation of the real onset times. (Figure

2.4) The reaction time was determined as the time difference between movement onset and EMG onset.

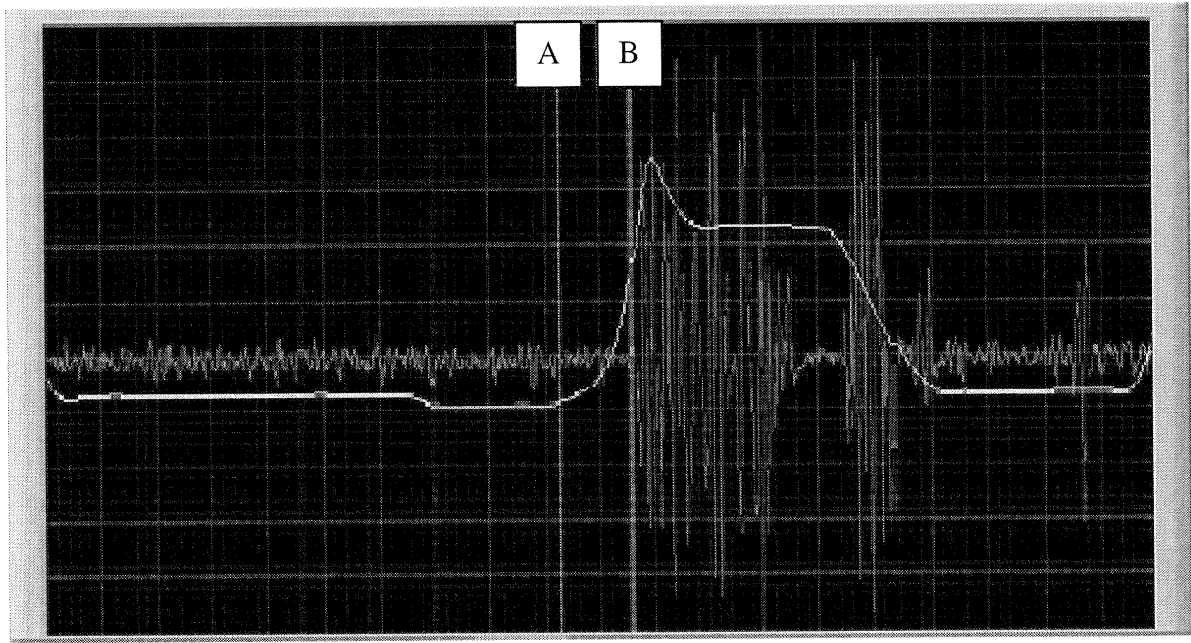


Figure 2.4 Visual analysis of reaction time of one muscle on one trial. The red line is the EMG signal and the white line is the position from the potentiometer. The yellow lines “A” and “B” represent the onset of inversion movement and the onset of EMG activity, respectively.

Statistical Analysis

The factors in this study were gender and test (pre and post fatigue). The dependent variables were muscle reaction time for each muscle tested. To evaluate and identify any differences in reaction time before and after fatigue and between genders, three separate 2x2 (Gender x Test) repeated measures analysis of variance (ANOVA) models, with repeated measures on the second factor, were completed, one

for each muscle (PL, PB, and TA) tested. A Bonferroni correction for multiple statistical tests was performed and statistical significance was set at $\alpha \leq 0.0167$ *a priori*.

Chapter 3

RESULTS

The mean reaction times for the TA, PL, and PB pre and post fatigue are presented in Table 3.1 and Figure 3.1. Table 3.2 includes the F statistics for the ANOVA. The ANOVA did not reveal any statistical differences between genders before and after fatigue for all three muscles. There were, however, significant main effects for test (pre and post fatigue) for both the PL and PB muscles, but not the TA. There were significant decreases (quicker response time) in the reaction times for both PL [F (1,18) = 9.405; P = 0.007] and PB [F (1,18) = 9.790; P = 0.006] after fatigue, demonstrating improvements rather than deficits. These main effects represent pooled values across both genders.

Table 3.1 Muscle reaction times before and after fatigue and the level of significance. * Indicates significance at P < 0.0167.

	Pre Fatigue	Post Fatigue	P-value
Tibialis Anterior	57.23±8.06 ms	54.63±10.01 ms	0.084
Peroneus Longus *	56.22±7.85 ms	52.71±10.52 ms	0.007
Peroneus Brevis *	58.72±7.62 ms	54.87±10.20 ms	0.006

Reaction Time after Fatigue

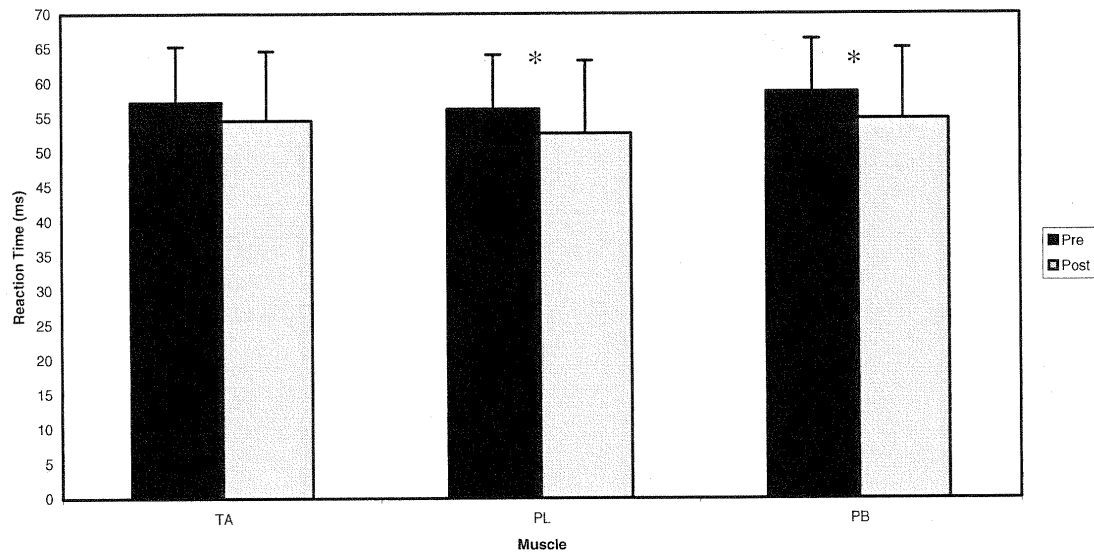


Figure 3.1 Reaction time values for the TA, PL, and PB muscles before and after fatigue. * Indicates significance at $P < 0.0167$.

Table 3.2 F-test statistics, effect size, and power for the three ANOVAs performed. All F-statistics have 1,18 degrees of freedom. * Indicates significance at $P < 0.0167$.

		F	P-value	Effect Size	Power
TA	Test	3.346	0.084	0.157	0.410
	Gender	0.103	0.752	0.006	0.061
	Test x Gender	0.466	0.504	0.025	0.099
PL	Test *	9.405	0.007	0.343	0.826
	Gender	0.015	0.904	0.001	0.052
	Test x Gender	0.114	0.740	0.006	0.062
PB	Test *	9.790	0.006	0.352	0.841
	Gender	0.030	0.864	0.002	0.053
	Test x Gender	0.042	0.840	0.002	0.054

Chapter 4

DISCUSSION

It was hypothesized that reaction time would increase (worsen), indicating deficits in the neuromuscular system during a fatigued state, which the results did not confirm. In fact, reaction time improved (decreased) in the two muscles that were fatigued. One possible reason for this finding is that the fatigue protocol focused only on one muscle group (peroneals), thus allowing the subjects to become more aware of his/her peroneal muscles, and any stimulus (inversion perturbation) to which they were subjected. The increased awareness, not only during the fatiguing event, but also during the actual perturbation, combined to possibly heighten the patients' conscious awareness of the peroneal muscles, thus preparing them for the reaction time measurements. Stimulus to one muscle group could cause a generalized increase in descending excitatory input, consequently improving the neural pathways supplying those muscles. It is also possible that the subjects experienced a learning effect from pre to posttest trials thereby improving reaction time after fatigue based solely on being more comfortable with and understanding the intricacies of the inversion perturbation device.²⁵ Further research is underway to examine the potential of learning and the impact on the perturbation results. Additionally, during brief perturbations, such as those used in this study, reaction time can decrease (improve) due to a transient increase in muscle spindle sensitivity in an effort to maintain function and force output after fatigue.²¹

One might contend that the isokinetic fatigue protocol utilized in this study did not produce fatigue. There is argument as to whether or not isokinetic fatigue protocols can simulate the “real-life” fatigue (functional fatigue) that occurs during sport participation. A previous study utilized the same isokinetic fatigue protocol used in this study and reported significant decreases in muscle force production, peak muscle activation, and median frequency following the fatigue intervention.⁴² Moreover, several studies have observed no significant differences between the type of protocol (isokinetic v. functional) used to induce fatigue and the time to stabilization of ground reaction forces during a jump landing task.^{40,43,44} Therefore, isokinetic fatigue protocols can be used to simulate the effects of fatigue induced during sport participation that is speculated to lead to an increased incidence of ankle injury.

The novelty of this study is the definition of fatigue: the subject was considered fatigued when a 50% decrease in ECC force production was noted in three consecutive trials. Given that ECC muscle actions are more resistant to force losses due to fatigue and the ECC action of the peroneal muscles when attempting to resist the inversion perturbation, using a decrease in ECC force production to measure fatigue is more applicable to the functional activities that give rise to ankle injuries. On the other hand, a 50% decrease in force production is dependent on the subject maintaining maximal effort during the pre-fatigue maximal strength trials. Subjects’ effort is always a limitation when maximal effort is required,⁴⁰ although the examiner tried to counteract this effect by providing verbal encouragement during the pre-fatigue maximal strength trials and throughout the duration of the isokinetic fatigue protocol. In addition, qualifying fatigue as a 50% decrease in eccentric force

production in three consecutive contractions minimized the effects of diminished effort. Oftentimes, the subjects force fell below 50% of the maximal ECC force production for one or two trials during the fatigue event, but subsequently increased following verbal encouragement from the examiner. Another limitation is that this study could have better controlled external factors and indicators of the onset of the inversion perturbation during the reaction time testing via the use of blindfolds and earplugs. Additionally, inclusion of a control group that performed pre and posttest inversion perturbations with a 5-minute rest in place of the fatigue intervention, may either confirm or deny any learning effect. Finally, as with most studies, additional subjects would offer more power to any significant results. In this study, there was only about a 4 millisecond decrease in reaction time for the PL and PB and about a 3 millisecond decrease in reaction time for TA. More subjects would increase the power and the difference in the TA may be significant. Also, one may ask whether 4 milliseconds would bear any clinical significance and if the slight decrease in reaction time would change the body's overall response to stress. It is not likely that 4 milliseconds would cause any drastic changes in the body's overall response, but further study is necessary to determine the clinical significance of these results.

There is some research evaluating the effect of fatigue on total motor time, which includes both premotor time and electromechanical delay, that supports our results.²⁵ Premotor time is the time delay between the onset of movement to the onset of EMG activity, which is what I defined as reaction time in this study, and electromechanical delay is the time between EMG activity onset and mechanical force production.²⁵ In a study of the vastus medialis muscle in response to fatigue, the premotor time significantly decreased while electromechanical delay significantly

increased, which lead to an insignificant change in total motor time.²⁵ Moore et al.²¹ conducted a similar study in the ankle looking at the response times of the peroneal muscles. In this case, premotor time was unaffected while both electromechanical delay and total motor time significantly increased.²¹ It has been proposed that central fatigue occurs when there is a decrease in new motor unit recruitment and/or a decrease in the firing frequency of the already active motor units.^{35,37} Peripheral fatigue, occurring beyond the neuromuscular junction, is due to diminished effectiveness of the contractile unit of the muscles.^{35,37} The changes in total motor time combine changes in premotor time, due to central fatigue, and electromechanical delay, due to peripheral fatigue.²⁵ As a result, it may be prudent to focus additional research on total motor time, monitoring both the premotor time and the electromechanical delay in response to fatigue of the ankle musculature. Furthermore, studying total motor time in response to a functional fatigue protocol may better simulate the fatigue that occurs during prolonged sports participation and may show differences in both the premotor time and the electromechanical delay.

It is interesting to compare the results presented in this study with those in other studies on reaction time during sudden ankle inversion. Reported mean reaction times for the lower leg muscles in response to an inversion perturbation range from 39.4 ms to 95.07ms.^{3-5,7,8,13-15,17,27-31} The average reaction time for this study ranged from 52.71ms to 58.72 ms. Discrepancies in the reported reaction times in this study and others could be due to a number of factors including small sample size, variations in methodology, and the operational definition of peroneal latency. Inversion perturbation platforms allow for varying degrees of motion from inverting only 5°⁷, to inverting 35°,⁴ to combining inversion with plantar flexion that displaces the foot 5 cm

from a level position.⁸ Peroneal latency represents the delay between the onset of the inversion perturbation and the onset of EMG activity. The discrepancy lies in the determination of the onset of EMG activity; which spans from visual inspection,⁸ two¹⁷ to ten⁴⁵ times the standard deviation of background noise, or 200% above background noise.⁴ This study utilized electrical activity ten times the standard deviation above background noise as the onset of EMG activity. Doing so minimized the effect of a noisy signal in the determination of onset times. Furthermore, all data were visually inspected to assure the proper detection of EMG onset.

The results confirmed the original hypothesis that there would be no differences in reaction times before or after fatigue between genders, as there was no significant main effect for gender nor was there an interaction between test and gender. Moore et al.²¹ found similar results when monitoring total motor time in response to a patellar-tendon-tap before and after an isokinetic fatigue intervention: there was no difference between males and females in premotor time before and after fatigue. However, there was a significant increase in electromechanical delay for females after fatigue and a significant decrease in response amplitude for males following fatigue.²¹ As aforementioned, it would be prudent to study total motor time, rather than reaction time exclusively, and also observe differences, if any, in both the reaction time and electromechanical delay between genders.

Chapter 5

CONCLUSION

It has been well documented that fatigue causes adverse effects on the neuromuscular system as evidenced by decreases in median frequency, force production, and postural sway.^{21,25,32-34, 36-39,46} Less research has been done on the premotor time, or reaction time, as a function of fatigue.^{21,25} This study only induced peripheral fatigue in one group of muscles, which led to a decrease in peroneal reaction time. Since other studies have found similar results when measuring total motor time and an increase in the electromechanical delay,^{21,25} it is possible that fatigue and its effects on neuromuscular control are mediated by the central nervous system; subsequently measures of central fatigue may be better suited to study. A functional fatigue protocol would more closely mimic the actions of the ankle musculature during athletic activities and would induce a more generalized (central) fatigue of the entire body. Generally, functional fatigue protocols require a longer testing session to induce fatigue than isokinetic fatigue protocols and are more likely to cause central fatigue.

The lateral ligaments, which are highly innervated by mechanoreceptors,^{11,13} along with the spindles in the peroneal muscles, perceive a stretch during inversion sprains and send an afferent signal to the spinal cord, which reflexively sends an efferent signal to the γ -motor neuron of the muscle spindle that sensitizes the muscle to stretch. Once the muscle is stretched, the muscle spindle reflex creates a contraction in the muscle to oppose the stretch.²² Comparing the

response of this reflex in healthy and functionally unstable ankles may be essential in determining the cause of ankle instability. The results show that this reflex is most likely mediated by the central nervous system and a fatigue protocol that not only induces peripheral, but also central, fatigue may provide valuable information regarding neuromuscular control in the ankle. Perhaps through a better understanding of these complex neurological interactions between the brain, spinal cord, and joint receptors, clinicians can improve prevention and treatment strategies.

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Appendix A

ANKLE INCLUSION QUESTIONNAIRE

Name: _____

Phone: _____

E-mail: _____

Subjective Criteria:

- | | | |
|--|---|---|
| 1. Have you ever had a previous ankle injury (sprains, strains, fractures, etc.)? | Y | N |
| 2. Have you ever had to use crutches due to a foot, ankle, knee injury; or for any reason? | Y | N |
| 3. Have you ever had the lower leg immobilized for any reason? | Y | N |
| 4. Do you ever have episodes of your ankle “giving way” or “rolling over” during daily activity (athletic or otherwise)? | Y | N |

Appendix B

INFORMED CONSENT

Informed Consent Agreement

Project Title: "Effect of Fatigue on Peroneal Reaction Time During Sudden Ankle Inversion"

Investigators: Thomas W. Kaminski, Gregory M. Gutierrez, and Nicole Surdam, Human Performance Laboratory, University of Delaware.

Please read this consent agreement carefully before you decide to participate in this study.

Purpose of the Research Study:

The purpose of this study is to examine muscle reaction time in the dominant ankle of healthy, uninjured individuals before and immediately after an intense bout of ankle exercise.

What You Will Do in the Study:

You are one of a total of 30 subjects ranging in age between 18-30 who has satisfied the criteria on the Ankle Study Inclusion Questionnaire completed previously. Upon reporting to the Human Performance Laboratory in the Fred Rust Ice Arena, we will ask you for basic personal information including age, height, weight, and sex. You will be asked to perform the following procedures associated with this study:

- Warm-up on a stationary bike for 5 minutes followed by completing a series of stretches for the legs in preparation for the testing.
- A pair of surface electrodes are then attached via a self-adhesive strip on the outer side of your dominant lower leg calf (the one with which you would kick a ball). These electrodes are used to measure electrical activity in your lower leg muscles as you complete the muscle reaction testing task. In order to create the best electrode contact with your skin, small patches of the skin's surface may require shaving with a disposable razor and cleansing with an alcohol swab.
- Once the electrodes are in place you will stand on a device that will quickly rotate your ankle back and forth. The device is driven by compressed air. We will be measuring how quickly your muscles respond to this sudden rotation. You will not know the precise moment the device is activated, but will be asked to stop your ankle from turning as soon as the motion occurs. A total of ten trials for the dominant ankle will occur at random intervals.
- You will then sit on the chair of the strength-testing device, while your foot is strapped to the footplate. After completing a series of warm-up repetitions to familiarize yourself with the device, you will perform six (6) ankle movements in succession (pushing the foot outward) at maximum effort. Only your dominant ankle will be tested.
- After this, you will perform a strength exercise routine that is similar to the strength testing, but will consist of moving your ankle continuously until our computer show a 50% reduction in effort.
- Immediately following this, your ankle reaction time will be tested in the same manner previously described.
- At the conclusion of the testing, you will be given time to again stretch your legs and relax.

Time Required:

One test session lasting approximately 2 hours.

Risks:

You may experience some mild muscle soreness in your lower legs at a period 24-48 hours after the test session. It is important that all warm-up and cool-down stretching exercises be performed as instructed to lessen the chances of this occurring. A minor risk of skin irritation may be associated with the shaving of the skin prior to

Subject Initials: _____
Date: _____
HSRU 11/05

*received
1/24/05
DA*

the attachment of the surface electrodes. The sudden and fast movements associated with the ankle movement device are novel, however the movement does not drop the ankle far enough to cause any harm. In the event of physical injury as a direct result of these research procedures, you will receive emergency medical treatment. If you require additional medical treatment, you will be responsible for the cost.

Benefits/Compensations:

There are no direct benefits to you for participating.

Confidentiality:

Data will be kept confidential. Your information will be assigned a code number. The list connecting your name to this number will be kept in a locked file. When the study is completed and the data have been analyzed, the list will be destroyed. Your name will not be used in any report.

Voluntary Participation:

Your participation in the study is completely voluntary. There is no penalty for not participating.

Right to Withdraw From the Study:

You have the right to withdraw from the study at any time without penalty.

Payment:

You will receive no payment for participating in the study.

Who to Contact if You Have Questions About the Study:

Dr. Thomas W. Kaminski, 302-831-6402
Gregory M. Gutierrez, 302-831-0003

Who to Contact About Your Rights in the Study:

Chair, Human Subjects Review Board, University of Delaware, 302-831-2136.

Agreement:

I have read the procedure described above. I voluntarily agree to participate in the procedure and I have received a copy of this description.

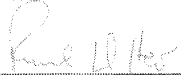
Participant: _____
Principal Investigator: _____

Date: _____
Date: _____

Subject Initials: _____
Date: _____
HSRB 10/05

Appendix C

HSRB APPROVAL

HUMAN SUBJECTS REVIEW BOARD ACTION	
University of Delaware Newark, DE 19716	
Protocol title:	Effect of Fatigue on Peroneal Reaction Time During Sudden Ankle Inversion
Principal investigator(s):	Thomas Kaminski; Health, Nutrition & Exercise Sciences
HSRB number:	HS 06-065
Type of review:	<input type="checkbox"/> Expedited <input checked="" type="checkbox"/> Full Board
The Human Subjects Review Board has reviewed the above-referenced protocol with respect to (1) the rights and welfare of the subjects; (2) the appropriateness of the methods to be used to secure informed consent; and (3) the risks and potential benefits of the investigation, and has taken the following action:	
<input type="checkbox"/> Approved without reservation	
<input checked="" type="checkbox"/> Approved as revised	
<input type="checkbox"/> Disapproved for reasons noted below	
Approval date:	November 29, 2005
Approval period:	11 months
Expiration date:	October 18, 2006 (One year from date of convened IRB meeting)
Submittal date for continuing review:	September 1, 2006
Changes in the protocol must be approved in advance by the HSRB.	
Comments:	
	Date <u>11/30/05</u>
Dr. Richard D. Holsten, Associate Provost for Research Chairman, Human Subjects Review Board 210 Hullahen Hall 302-831-2383, fax: 302-831-2828, rholsten@udel.edu	